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TITLE: Method of localization refinement of pattern images using optical flow constraints

Abstract Text (1):

A method for localization refinement of inspection patterns comprises the steps of providing a template image comprising pixels in a pattern, each pixel having an intensity, providing an input image having a same pattern of pixels as the template image and calculating an energy function by weighting a sum of modified optical flow constraints at locations of the pixels of both the template image and the input image to determine a shift and rotation between the pattern of the template image and the input image.

Application Filing Date (1):

19971218

Brief Summary Text (8):

In one proposal, an image registration technique is performed by fitting feature points in the zero-crossings extracted from the image to be inspected to the corresponding points extracted from the CAD model via an affine transformation. Unfortunately, the correspondence between the two set of feature usually cannot be reliably obtained. Another proposal employed a sum-of -squared-differences (SSD) method to determine the shift between the two images. In addition to its restriction on the recovery of shift alignment only, this method could not handle illumination changes between the image to be inspected and the reference image.

Brief Summary Text (12):

A method for localization refinement of inspection patterns includes the steps of providing a template image comprising pixels in a pattern, each pixel having an intensity, providing an input image having a same pattern of pixels as the template image and minimizing an energy function formed by weighting a sum of modified optical flow constraints at locations of the pixels of both the template image and the input image to determine a shift and rotation between the pattern of the template image and the input image.

Brief Summary Text (13):

In other methods, the steps may include partitioning the template image into blocks of pixels, determining a reliability measure for each pixel in each block and identifying the pixel location for each block having a largest reliability measure as the feature point for each block.

Brief Summary Text (17):

In other methods, the step of determining feature points may include partitioning the template image into blocks of pixels, determining a reliability measure for each pixel in each block and identifying the pixel location for each block having a largest reliability measure as the feature point for each block. The step of minimizing an energy function formed by weighting a sum of modified optical flow constraints at locations of the feature points further includes the steps of calculating a Hessian matrix and a gradient vector of the energy function based on an initial guess of a shift and a rotation, updating the initial guess based on the

calculating the Hessian matrix and the gradient vector of the energy function and iteratively recalculating the Hessian matrix and the gradient vector of the energy function until an updated guess is within an acceptable increment from a previous updated guess. The step of smoothing the template image to reduce noise effects may also be included. The step of minimizing an energy function formed by weighting a sum of modified optical flow constraints at locations of the feature points may further include the step of incorporating an illumination change factor into the optical flow constraints for accounting for pixel intensity changes due to illumination effects.

Brief Summary Text (18):

A method for computer inspection for determining misalignment between inspection patterns includes the steps of providing a template image comprising blocks of pixels, determining features points on the template image from among blocks of pixels by selecting a pixel location in each block having a largest reliability measure, averaging pixels in an area surrounding each feature point to reduce noise in the template image, providing an input image with an initial shift and rotation guess to the template image, minimizing an energy function formed by weighting a sum of modified optical flow constraints at locations of the feature points of the template image to determine a shift and rotation between the template image and the input image. The step of minimizing an energy function formed by weighting a sum of modified optical flow constraints at locations of the feature points may further include the steps of calculating a Hessian matrix and a gradient vector of the energy function based on an initial guess of a shift and a rotation, updating the initial guess based on the calculating the Hessian matrix and the gradient vector of the energy function and iteratively recalculating the Hessian matrix and the gradient vector of the energy function until an updated guess is within an acceptable increment from a previous updated guess. The step of minimizing an energy function formed by weighting a sum of modified optical flow constraints at locations of the feature points may further include the step of incorporating an illumination change factor into the optical flow constraints for accounting for pixel intensity changes due to illumination effects.

Detailed Description Text (5):

A modified optical flow constraint is derived herein by using a generalized brightness assumption and replacing displacement vectors by the 2D rigid transformation parameters. Based on the consideration of efficiency as well as reliability, a feature point selection method is used to choose a set of locations with reliable modified optical flow constraints. The method is primarily based on an iterative energy minimization formulation with an energy function being a weighted sum of modified optical flow constraints at selected locations. The method handles large degrees of illumination changes by explicitly incorporating an illumination change factor into the modified optical flow constraint. The minimization of the energy function is accomplished via an efficient iterative algorithm, which has proved to be very reliable for small localization refinement from experiments described herein, namely for position errors within 5 pixels and rotation angles within 5 degrees. The minimization process is basically a very efficient search of the best transformation, i.e. shift and rotation, for general template matching.

Detailed Description Text (33):

This gives a sum-of-squared-differences error, which is a measure of absolute distance between points within each block. Since it is more reasonable to use a measure of minimum distance, the sum of squared linear approximation errors $sse(x, y)$ is normalized by using the magnitude of the gradient of the linear function $\alpha x + \beta y + \gamma$ to obtain a measure of minimum distance, i.e. $sse(x, y) / (\alpha^2 + \beta^2)$. A reliability measure $\sigma(x, y)$ of using the modified optical flow constraint at location (x, y) may be defined as follows:
##EQU12##

Detailed Description Text (42):

Referring now in specific detail to the drawings in which like reference numerals identify similar or identical elements throughout the several views, and initially to FIG. 1, a flow chart 10 of localization refinement steps of the method in accordance with the disclosure of the present invention is illustrated. The implementation of a localization refinement algorithm includes two phases, namely a training phase 6 and execution phase 8. The training phase 6 includes a template object step 12, where a template object is recovered, a preprocessing or smoothing step 14, a feature selection step 16 which includes the computation of the gradients to determine the feature point locations for the template image. The computation involved in this phase is completely related to the template image only, therefore it can be performed in advance of the capture of the input image. Since the templates in many industrial inspection applications were already known prior to starting the localization task, the training phase 6 for these templates can be pre-computed beforehand.

Detailed Description Text (44):

The execution phase 8 is basically an iterative energy minimization process step 20 to estimate the shift and rotation angle difference between an input image from step 22 and the template image. The shift and rotation angle difference are outputted in step 24. The total time required in the execution phase 8 of the algorithm is independent of the size of the image. It depends on the number of feature points and the number of iterations required in the energy minimization process. In our experiments, the execution phase takes about 20.about.30 msec on a multi-user SUN SPARC-20 workstation, depending on the number of iterations required to achieve the convergence in the energy minimization process.

Detailed Description Text (46):

Referring to FIG. 1C, step 20 of FIG. 1A may include substeps for calculating the Hessian matrix and the gradient vector of the energy function (E or E'). Details of these steps are described above. In step 34, modified optical constraints are calculated for each pixel or each feature point. In step 36, the modified optical flow constraints are weighted. The Hessian matrix and the gradient vector of E or E' is calculated in step 38 based on an initial guess (.DELTA.x.sup.(0), .DELTA.y.sup.(0), .theta..sup.(0)) from step 22. A new guess is calculated using the Newton method, for example, in step 40. In steps 42 and 44, the new guess is compared to the previous guess to determine if an acceptable increment has been achieved, for example, the changes in the x- and y- shifts are within about 0.1 pixels and the change in the rotation angle is within about 0.1 degrees. If the guess is within the acceptable increment, (.DELTA.x, .DELTA.y, .theta.) are outputted in step 24 (FIG. 1A). If the guess is not within the acceptable increment, steps 38, 40, 42 and 44 are repeated.

Detailed Description Text (48):

Referring to FIGS. 2A, an illustrative inspection pattern is shown for a "pound sign". In FIGS. 2B and 2C, transformations were randomly generated (including shifts and rotations) for each template with the shifts in the x and y directions randomly selected from a uniform distribution ranging from -5 to 5 pixels and the rotation angles drawn from a uniform distribution between -5 to 5 degrees. Global illumination changes were simulated by randomly drawing samples for the coefficients a and b in the illumination change model from the uniform distributions of the ranges [0.75, 1.25] and [30, -30]. To simulate a noise effect, a random is multiplicative noise was imposed to each pixel with each multiplication factor randomly selected from two different uniform distributions in the ranges between -10% to 10% of multiplicative noise (FIG. 2B), and -20% to 20% of multiplicative noise (FIG. 2C), to show the accuracy of the estimation under different levels of noises. After the above simulation processes, the intensity values were rounded to the closest integer values between 0 and 255.

Detailed Description Text (49):

To alleviate the noise effect, a simple smoothing operation may be performed on the template image simply by averaging in a 3.times.3 window, for example. Then, the iterative energy minimization method is applied to estimate the shift and rotation. In one example, with the convergence criterion that the changes in the x- and y_ shifts are within 0.1 pixels and the change in the rotation angle is within 0.1 degrees, the minimization usually converges in about 10 iterations.

Detailed Description Paragraph Table (1):

TABLE 1 Mean Standard Deviation Errors in .DELTA.x -0.014 pixels 0.035 pixels
Errors in .DELTA.y -0.015 pixels 0.047 pixels Errors in .theta. -0.006 degrees
0.019 degrees

Detailed Description Paragraph Table (2):

TABLE 2 Mean Standard Deviation Errors in .DELTA.x -0.016 pixels 0.057 pixels
Errors in .DELTA.y -0.016 pixels 0.065 pixels Errors in .theta. -0.008 degrees
0.028 degrees

Detailed Description Paragraph Table (3):

TABLE 3 Mean Standard Deviation Errors in .DELTA.x -0.026 pixels 0.035 pixels
Errors in .DELTA.y -0.003 pixels 0.016 pixels Errors in .theta. -0.002 degrees
0.013 degrees

Detailed Description Paragraph Table (4):

TABLE 4 Mean Standard Deviation Errors in .DELTA.x -0.027 pixels 0.042 pixels
Errors in .DELTA.y -0.010 pixels 0.030 pixels Errors in .theta. -0.004 degrees
0.015 degrees

CLAIMS:

1. A method for localization refinement of inspection patterns comprising the steps of:

providing a template image comprising pixels in a pattern, each pixel having an intensity; partitioning the template image into blocks of pixels;

determining a reliability measure for each pixel in each block, the reliability measure being based upon a sum of the squares error and a polynomial fitting function for the pixels in the block;

identifying a pixel location for each block having a largest reliability measure as a feature point for each block;

providing an input image having a same pattern of pixels as the template image, the input image having an initial shift and rotation relative to the template image;

modifying optical flow constraint equations to account for illumination changes in the input image; and

minimizing an energy function formed by weighting a sum of the modified optical flow constraints at locations of the pixels of both the template image and the input image to determine a shift and rotation between the pattern of the template image and the input image for determining misalignments between the template image and the input image for an inspection process the minimizing step being performed at locations of the feature points of the template image to determine the shift and rotation between the template image and the input image.

5. A method for localization refinement of inspection patterns comprising the steps of:

determining features points on a template image from among blocks of pixels by:

partitioning the template image into blocks of pixels;

determining a reliability measure for each pixel in each block, the reliability measure being based upon a sum of the squares error and a polynomial fitting function for the pixels in the block;

identifying the pixel location for each block having a largest reliability measure as the feature point for each block;

providing an input image with an initial shift and rotation relative to the template image;

modifying optical flow constraint equations to account for illumination changes in the input image; and

minimizing an energy function formed by weighting a sum of the modified optical flow constraints at locations of the feature points of the template image to determine a shift and rotation between the template image and the input for determining misalignments between the template image and the input image for an inspection process, the minimizing step being performed at locations of the feature points of the template image to determine the shift and rotation between the template image and the input image.

9. A method for computer inspection for determining misalignment between an inspection pattern an object with a pattern to be inspected comprising the steps of:

providing a template image for the inspection pattern comprising blocks of pixels;

determining features points on the template image from among blocks of pixels by selecting a pixel location in each block having a largest reliability measure the reliability measure being based upon a sum of the squares error and a polynomial fitting function for the pixels in the block;

averaging pixels in an area surrounding each feature point to reduce noise in the template image;

providing an input image for the object with a pattern to be inspected with an initial shift and rotation guess with respect to the template image;

modifying optical flow constraint equations to account for illumination changes in the input image; and

minimizing an energy function formed by weighting a sum of the modified optical flow constraints at locations of the feature points of the template image to determine a shift and rotation between the template image and the input image for determining misalignments between the template image and the input image for an inspection process.